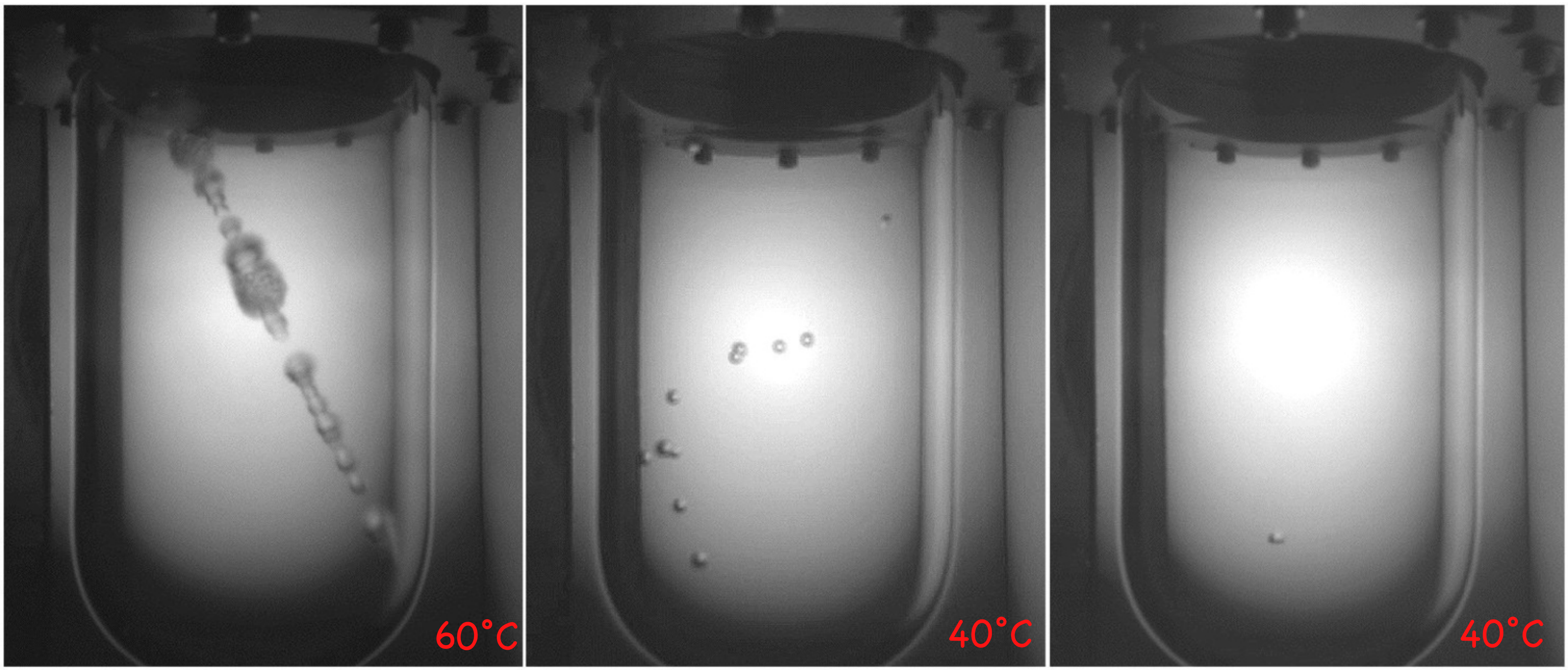
COUPP-500: towards a ton-scale bubble chamber for DM detection

Moderately superheated BC's for dark matter detection:

Conventional BC operation
(high superheat, MIP sensitive)

Low degree of superheat, <u>sensitive to nuclear recoils only</u>



muon | Neutron | WIMP

ultra-clean BC: Bolte *et al.*, NIM A577 (2007) 569

COUPP approach to WIMP detection:

- Detection of single bubbles induced by high-dE/dx nuclear recoils in heavy liquid bubble chambers

- <10^{-10} rejection factor for MIPs. *INTRINSIC* (no data cuts)

- Scalability: large masses easily monitored (built-in "amplification"). Choice of three triggers: pressure, acoustic, motion (video))

- Revisit an old detector technology with improvements leading to extended (unlimited?) stability (*ultra-clean* BC)

- Excellent sensitivity to both SD and SI couplings (CF_3I)

- Target fluid can be replaced (e.g., C_3F_8, C_4F_{10}, CF_3Br). Useful for separation between n- and WIMP-recoils and pinpointing WIMP in SUSY parameter space.

- High spatial granularity = additional n rejection mechanism

- Low cost, room temperature operation, safe chemistry (fire-extinguishing industrial refrigerants), moderate pressures (<200 psig)

- Single concentration: reducing or rejecting α-emitters in fluids to levels already achieved elsewhere (~10^{-17}) will lead to complete probing of SUSY models

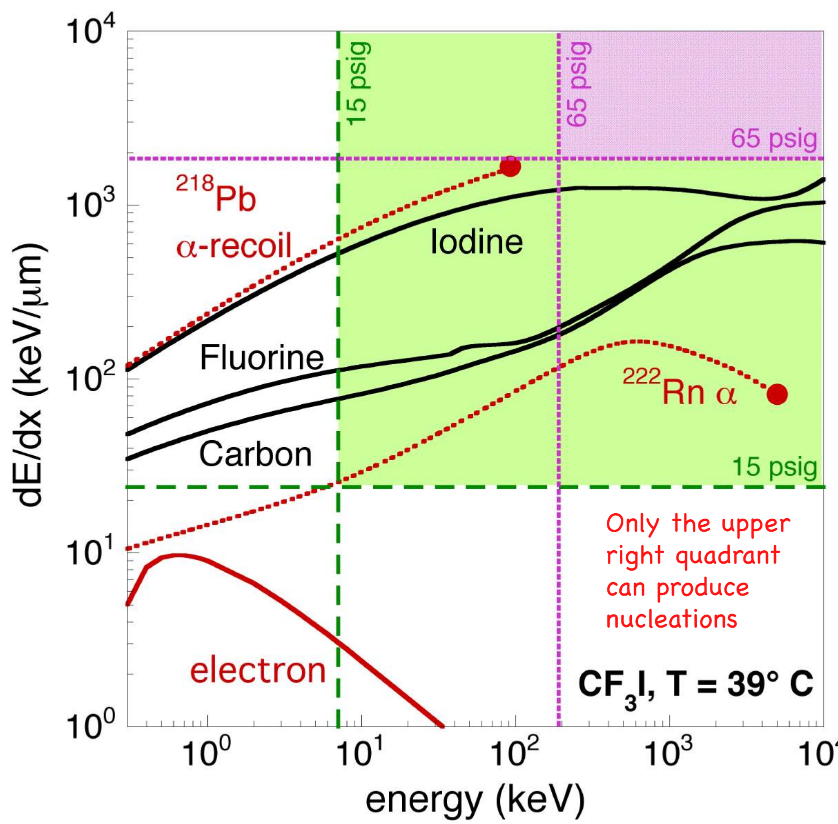
Seitz model of bubble nucleation (classical BC theory):

Threshold in deposited energy

$$E > E_c = 4\pi r_c^2\left(\gamma - T\frac{\partial\gamma}{\partial T}\right) + \frac{4}{3}\pi r_c^3 \rho_v \frac{h_{fg}}{M} + \frac{4}{3}\pi r_c^3 P \quad , \quad r_c = 2\gamma/\Delta P$$

$$\mathrm{d}E/\mathrm{d}x > E_c/(a r_c)$$

Threshold also in stopping power, allows for efficient INTRINSIC MIP background rejection



COUPP approach to WIMP detection:

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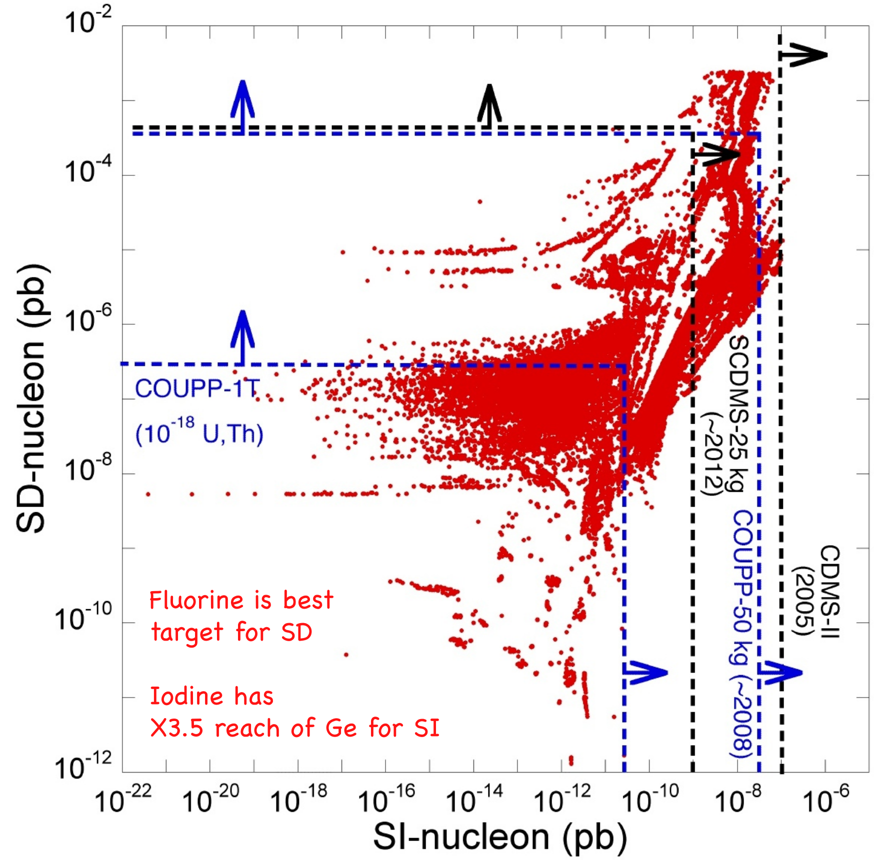
An old precept: attack on both fronts

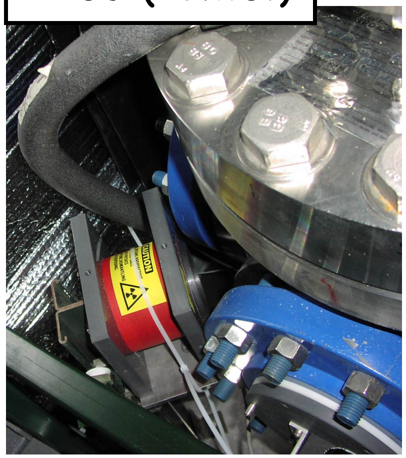


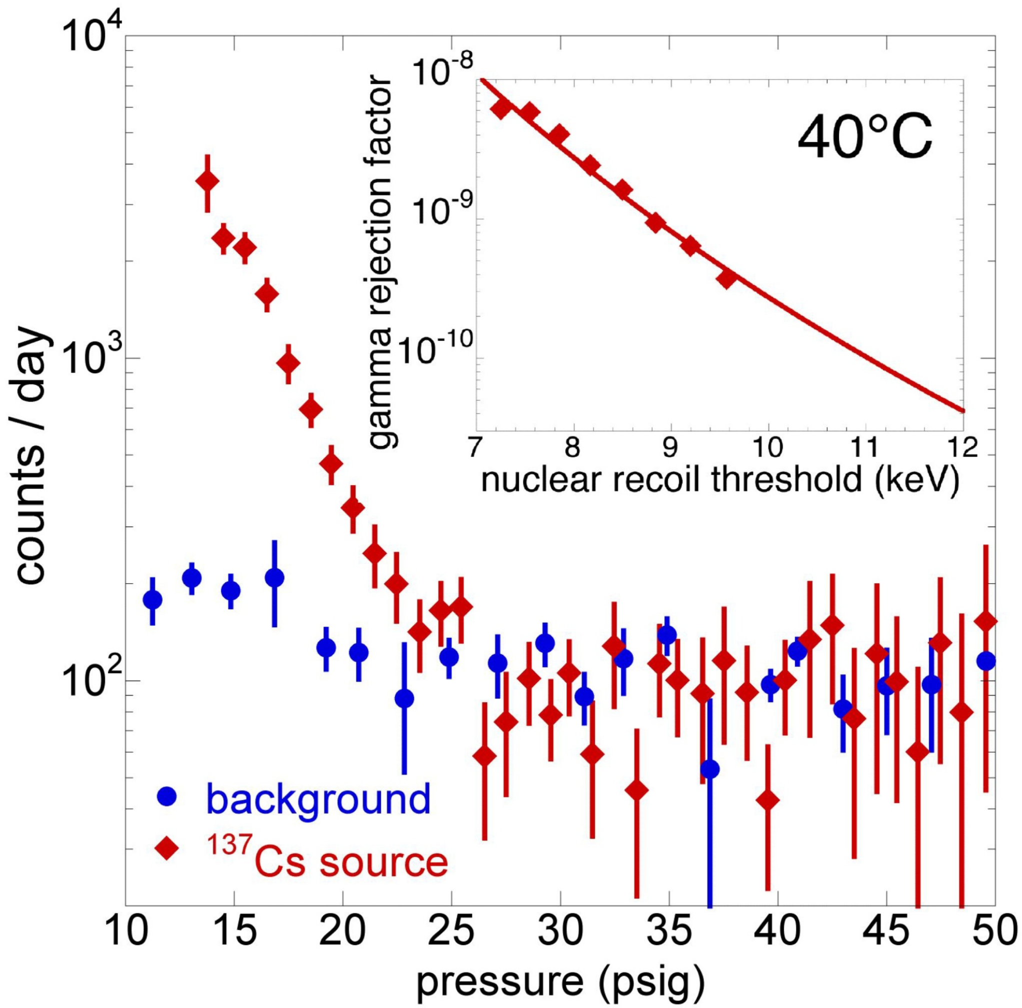
Baltz & Gondolo, JHEP 0410:052,2004. (WMAP-II update)

SD SUSY space harder to get to, but predictions are more robust and phase-space more compact. Worth the effort. (astro-ph/0001511, 0509269, and refs. therein)

E-961 progress: gamma and neutron calibrations

^{137}Cs (13mCi)





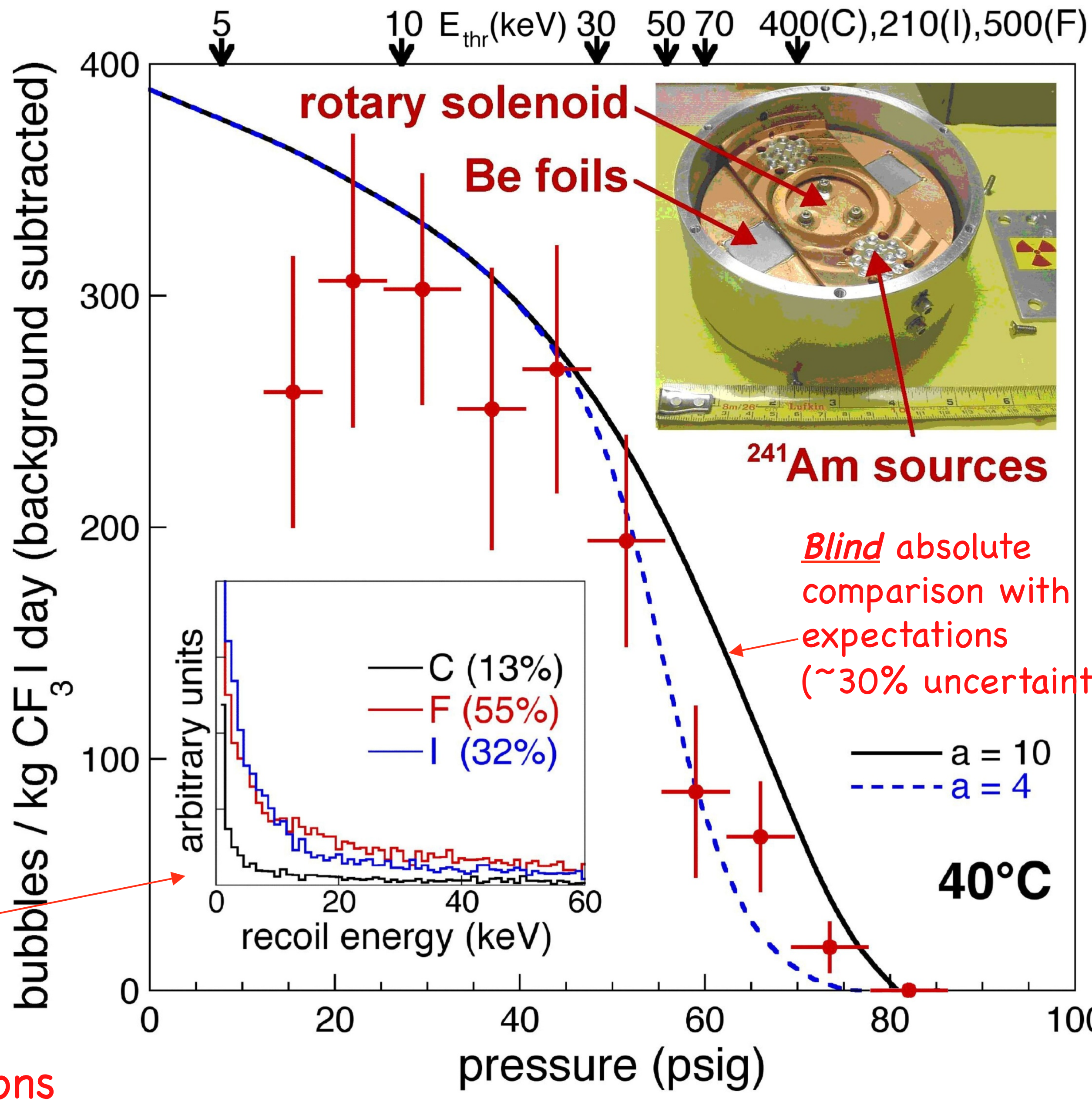
Best MIP rejection factor measured anywhere ($<10^{-10}$ INTRINSIC, no data cuts)

Other experiments as a reference:
XENON ~10^{-2}-10^{-3}
CDMS 10^{-4}–10^{-5}
WARP ~10^{-7}-10^{-8}

^{14}C betas not an issue for COUPP (typical O(100)/kg-day)
<u>No need for high-Z shield</u>
<u>nor attention to chamber material selection</u>
<u>(...for the time being!)</u>

E-961 progress: gamma and neutron calibrations

Switchable Am/Be (5 n/s)

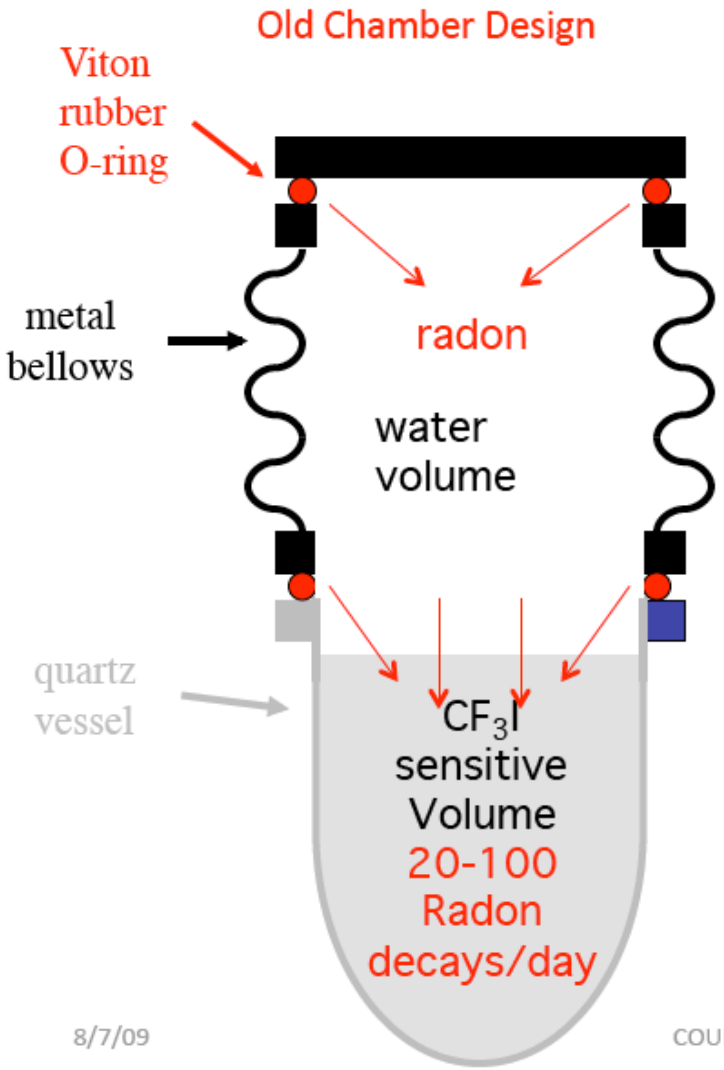


Blind absolute comparison with expectations (~30% uncertainty in those)

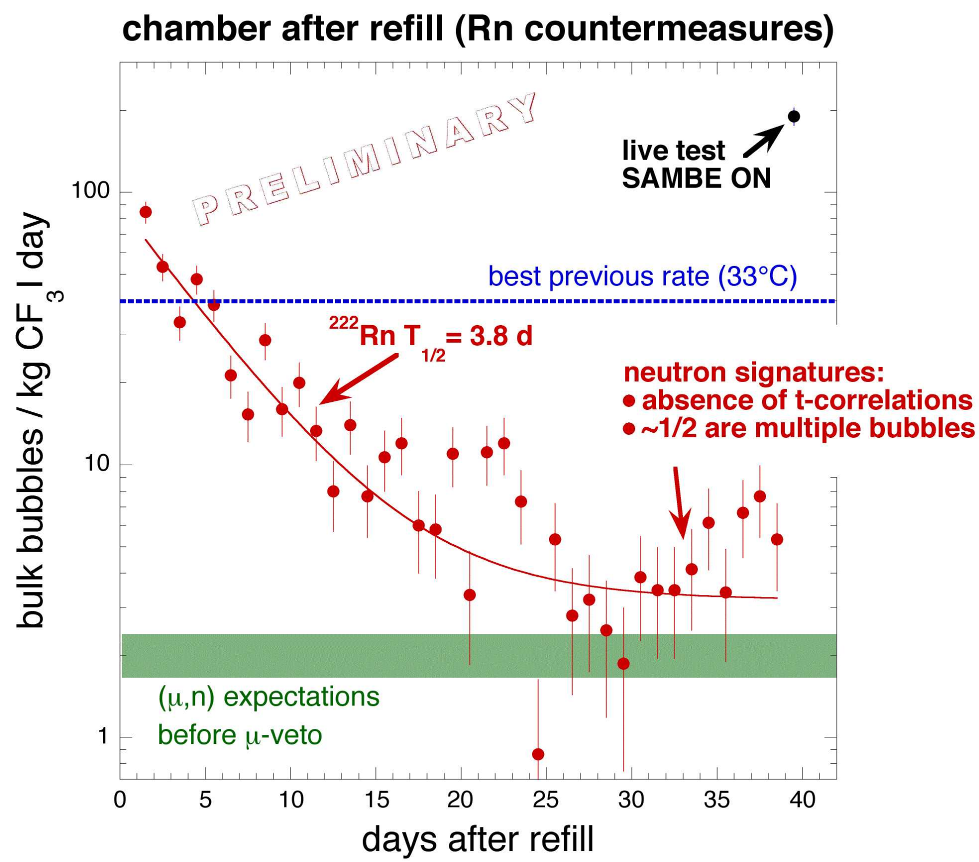
Low-energy WIMP-like recoil energy signal used in these calibrations

E-961 progress: Rn control

2-kg Chamber 2008 Data



- Radon greatly reduced by replacement of Viton O-rings with metal seals.
- We begin to see backgrounds from cosmic-ray coincident neutrons

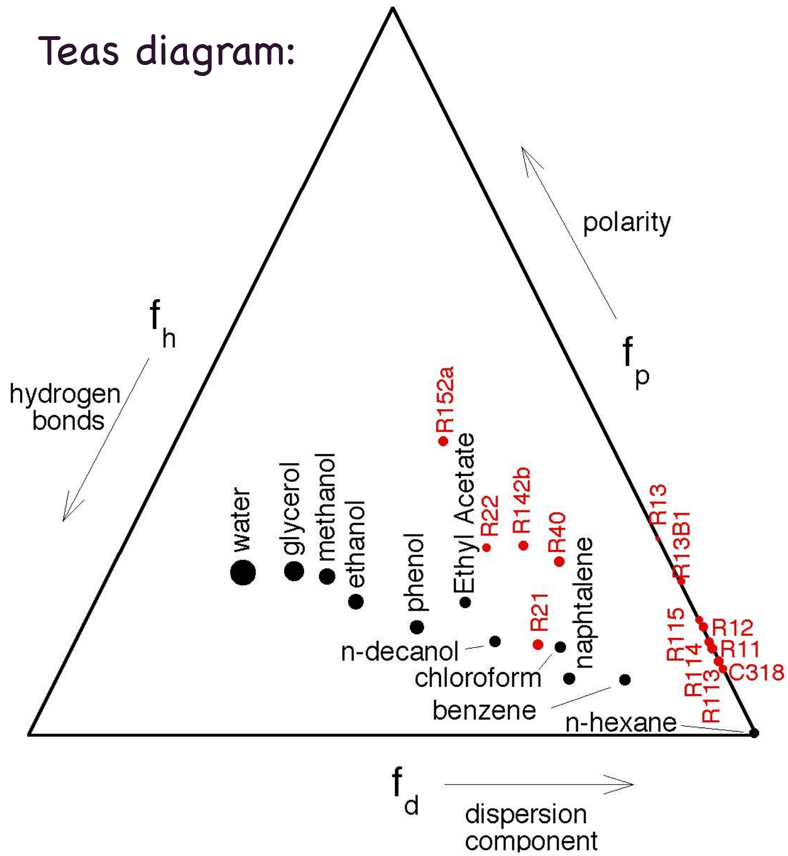


E-961 progress: fluid purification & handling

"like dissolves like"

U & Th salts readily dissolve in H_2O, refrigerants do not. <u>**Solubility of U,Th in CF_3I expected to be very small**</u> (a situation similar to mineral oil-based ν dets.)

Teas diagram:



Fractional cohesion parameters for refrigerants and common solvants (size of marker ~ δ_t)

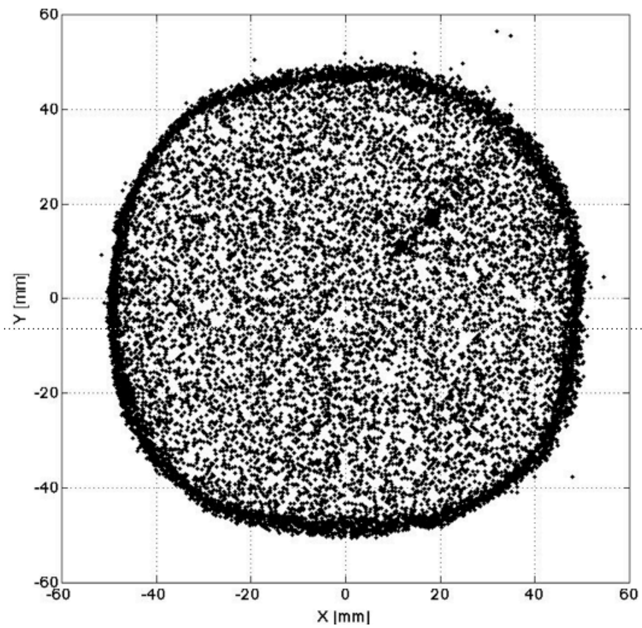
First serious attempt at fluid handling/purification, commissioned during NUMI 60-kg fill.

So far we have only profited from SNOlab water availability (to reach already <5 α-like ev/kg-day)

We foresee most future effort on H_2O purification.

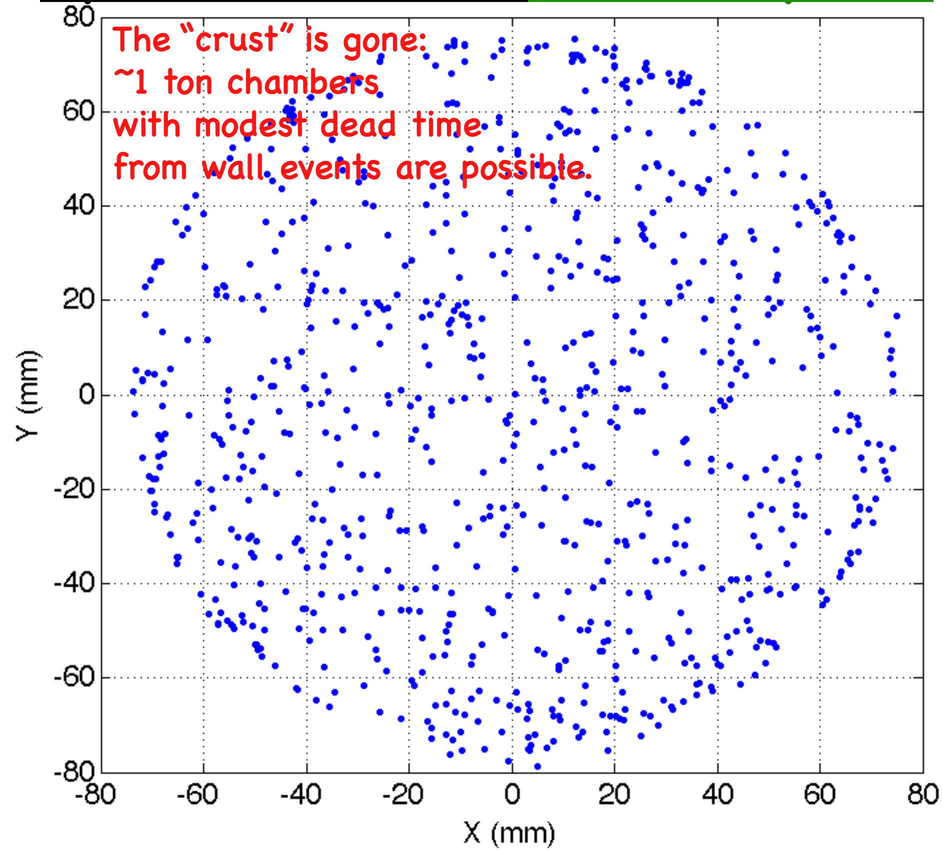
E-961 progress: wall events a thing of the past

Natural Quartz: 0.8/day/cm²



~40 live-days (2007-08)

Synthetic Silica: ≤1e-2/day/cm²



88 live-days (2009)

- We detected a ~50 ppb U,Th contamination in regular quartz used in early chambers.
- Alpha emission from surface was independently confirmed, at the same rate as wall evts.
- New chambers now featuring synthetic silica (~3 orders of magnitude lower U,Th content)
- New rate will allow us to reach 1 ton without any live-time penalty.
- Synthetic silica vessels available up to 250kg CF3I: extrapolation to ~500kg part of our DUSEL S4 charge. UPDATE: vessels up to >1 m³ may be readily available.

E-961 progress: alpha – nuclear recoil discrimination

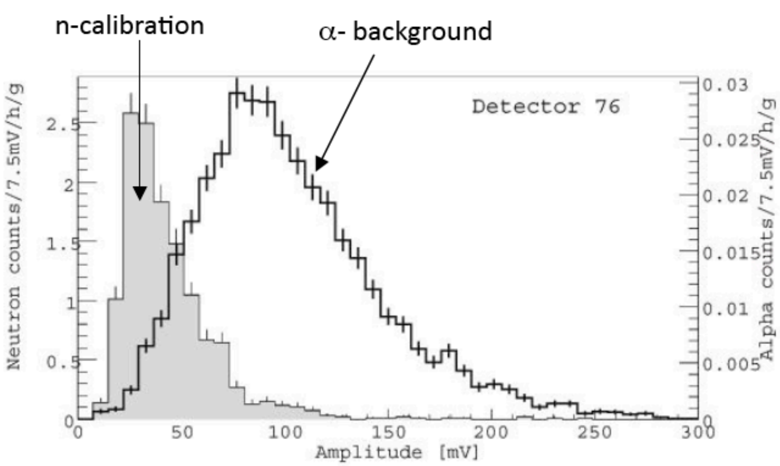
Glaser (1955)

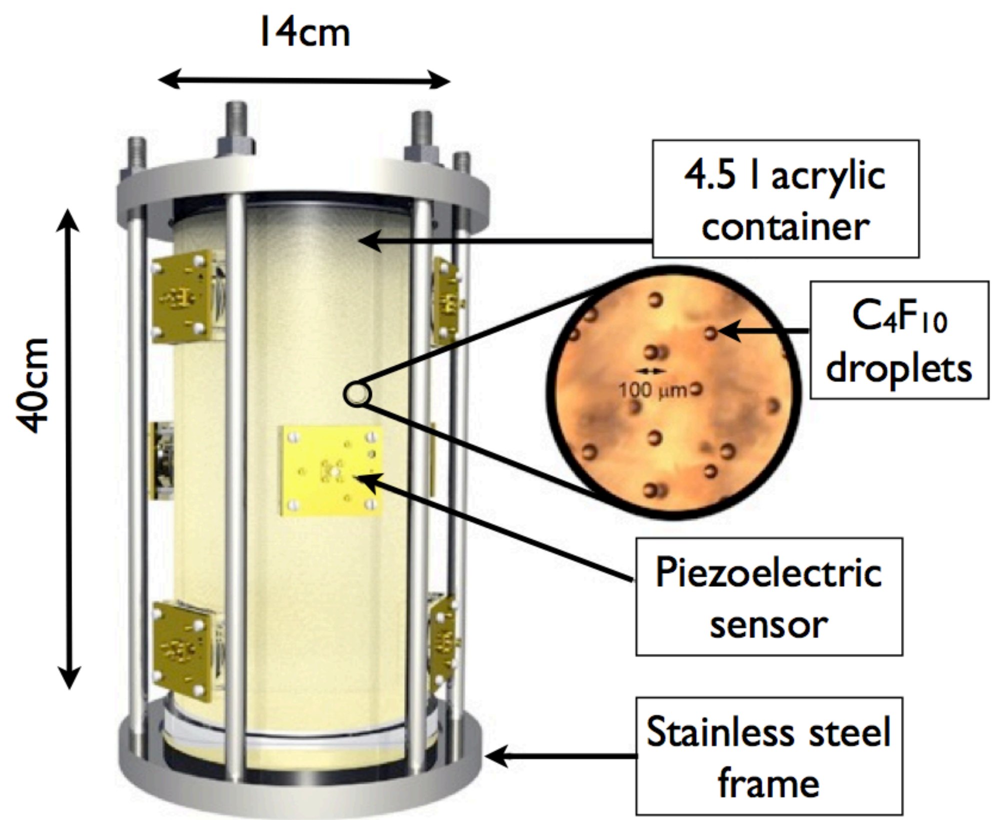
In order to see events more interesting than muons passing straight through the chamber, we took advantage of the violence of the eruption which produces an audible "plink" at each event. A General Electric variable-reluctance phonograph pickup was mounted with its stylus pressing against the wall of the chamber. Vibration signals occurring during the quiescent period after the expansion were allowed to trigger the lights and take pictures. In this way we saw tracks of particles passing through the chamber in various directions,

Martynyuk & Smirnova (1991)

The initial pressure in the volume V depends on the energy transmitted by the particle to that volume. Consequently, the characteristics of the acoustic pulse depend on the parameters of the particle responsible for formation of the bubble….
The parameters of these pulses must depend strongly on the characteristics of the particle.

PICASSO collab. (2009)





PICASSO demonstrates α – nuc. recoil acoustic discrimination in Superheated Droplet Detectors (SDDs)
F. Aubin *et al.*, New J. Phys 10 (2008) 103017

E-961 progress: alpha – nuclear recoil discrimination

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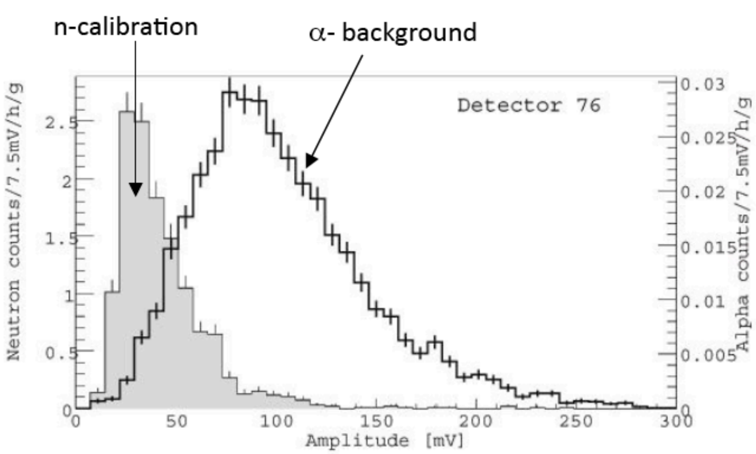
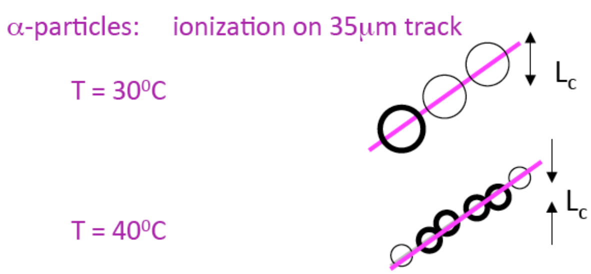
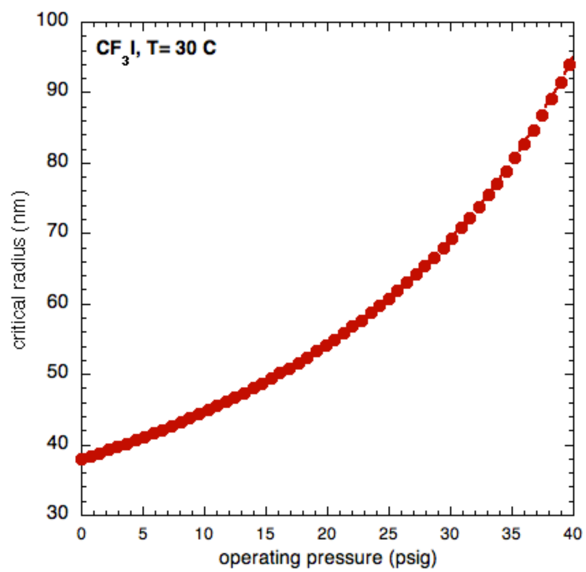
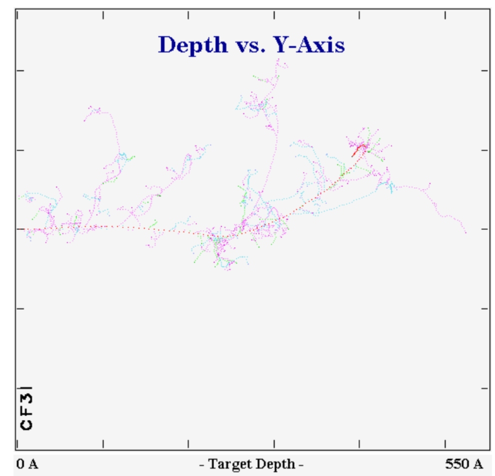




10 keV iodine recoil spans ~50 nm = ~1 critical radius (can create only ~one protobubble)

Alpha particles can create several along their much longer paths (one guaranteed, the α-recoil).

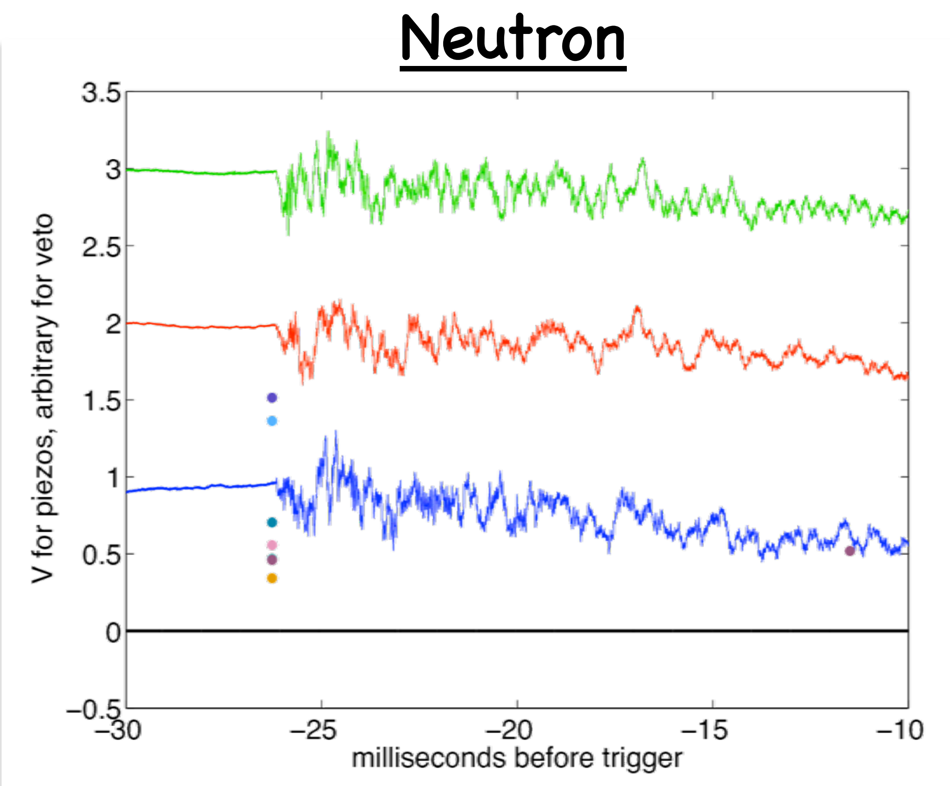


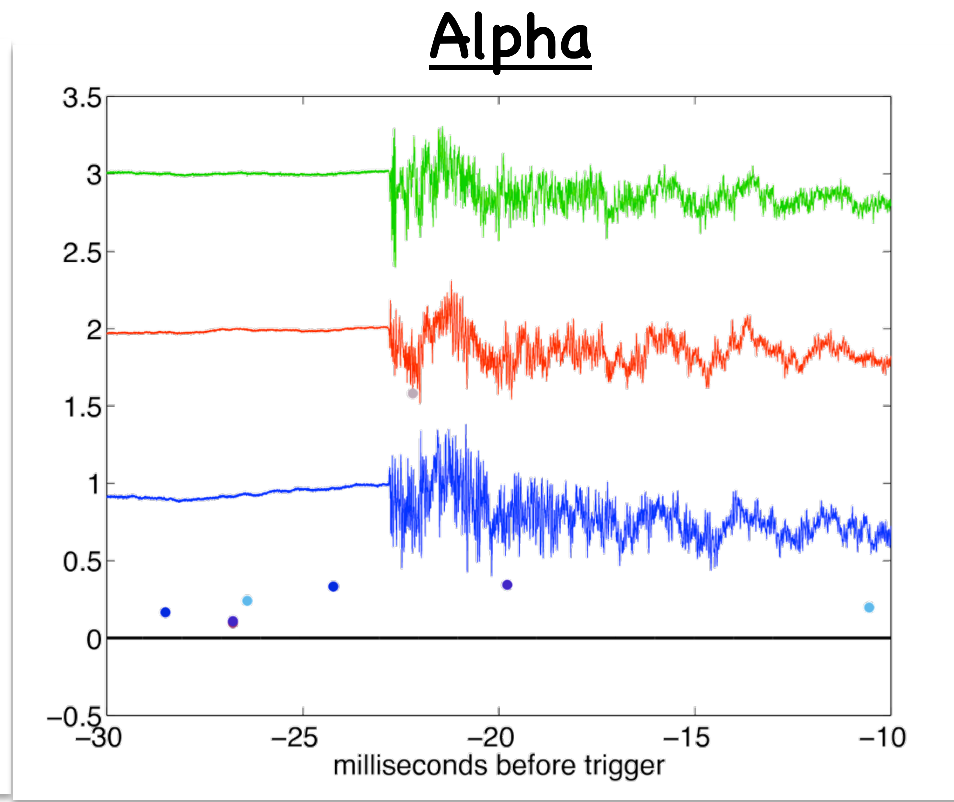


As exciting as the SDD PICASSO results are, we expected the effect to be much more dramatic in a BC...

- no alpha energy loss in gel, nor partial trajectory through droplet
- SDDs are an acoustically dispersive medium
- BC transparency allows for spatial corrections
- effect expected to be larger at freq. beyond Picasso piezo bandwidth.

E-961 progress: acoustic alpha - nuclear recoil discrimination





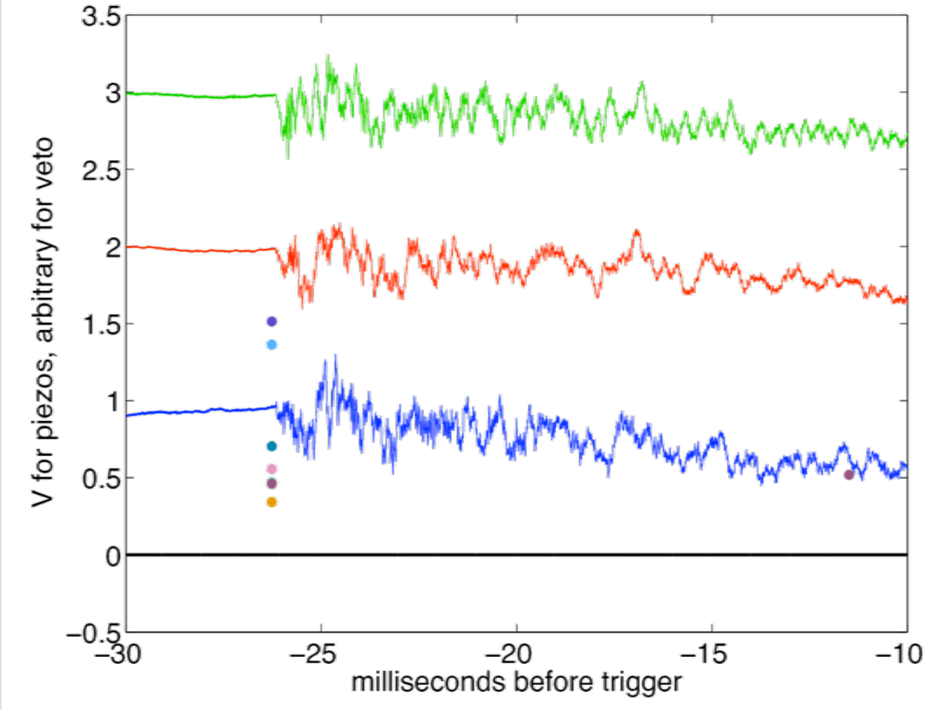
We observe two distinct families of single bubble bulk events in a 4 kg chamber:

- Discrimination increases with frequency, as expected.
- We have a handle on which is which (Rn time-correlated pairs following injection, S-AmBe calibrations, NUMI-beam events).
- Polishing off the method, but potential for high discrimination against α's is clear.
- Challenge in obtaining same discrimination in the 60kg device: increasing sensors to 24, also their bandwidth (IUSB group)

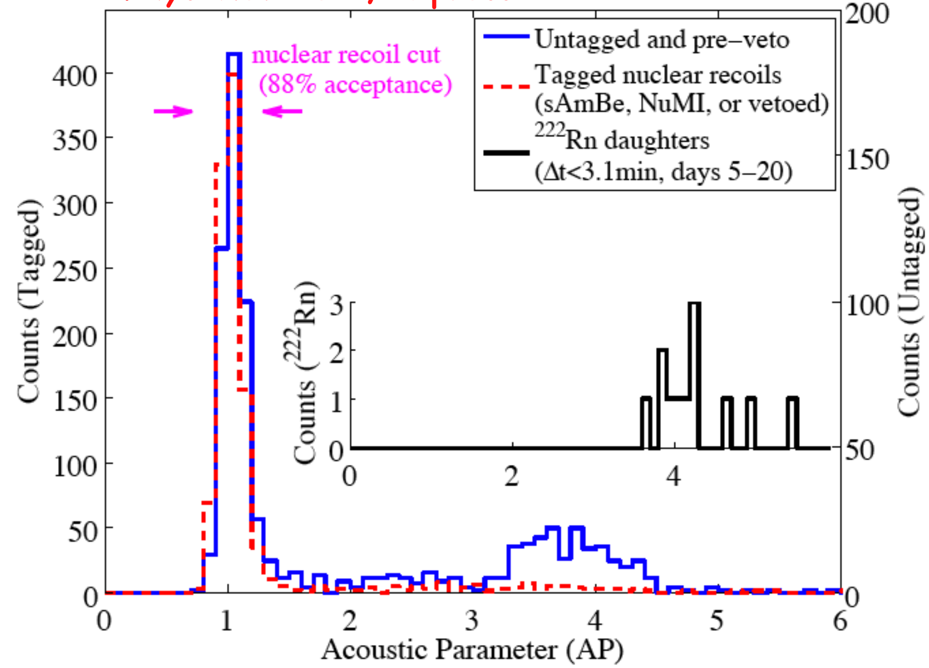
A zero-background experiment soon?

E-961 progress: acoustic alpha - nuclear recoil discrimination

Neutron



Phys. Rev. Lett., in press



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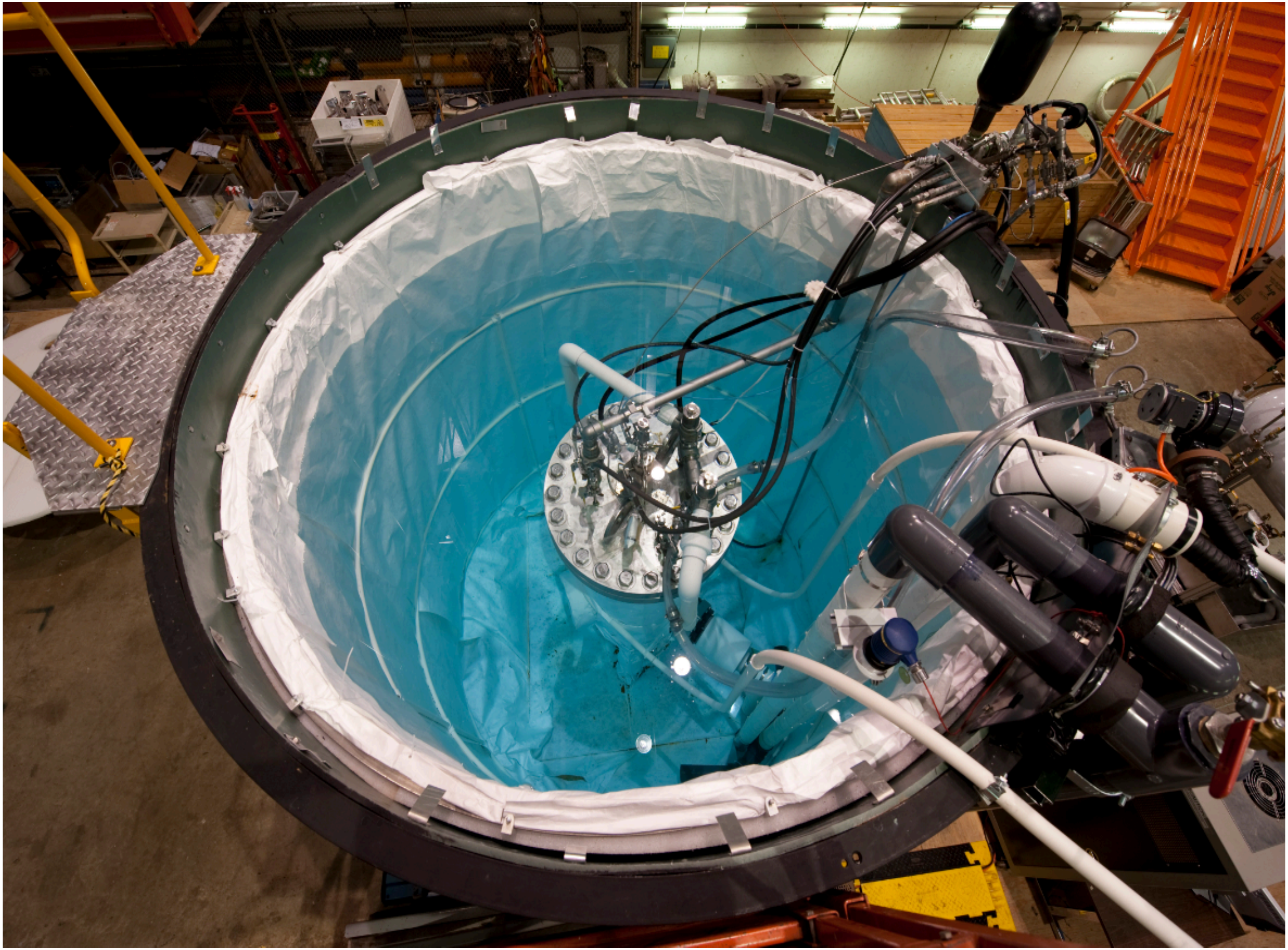
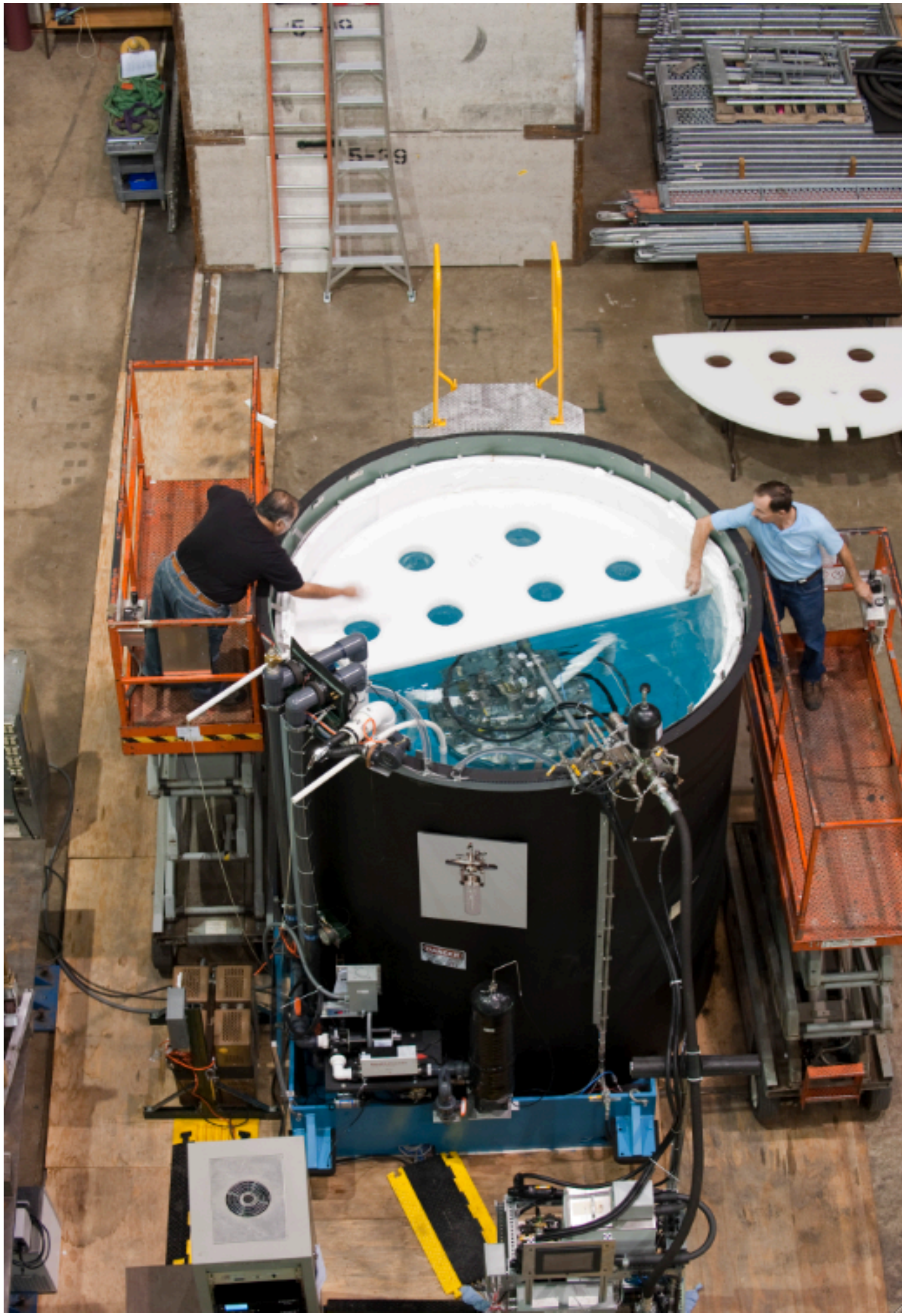
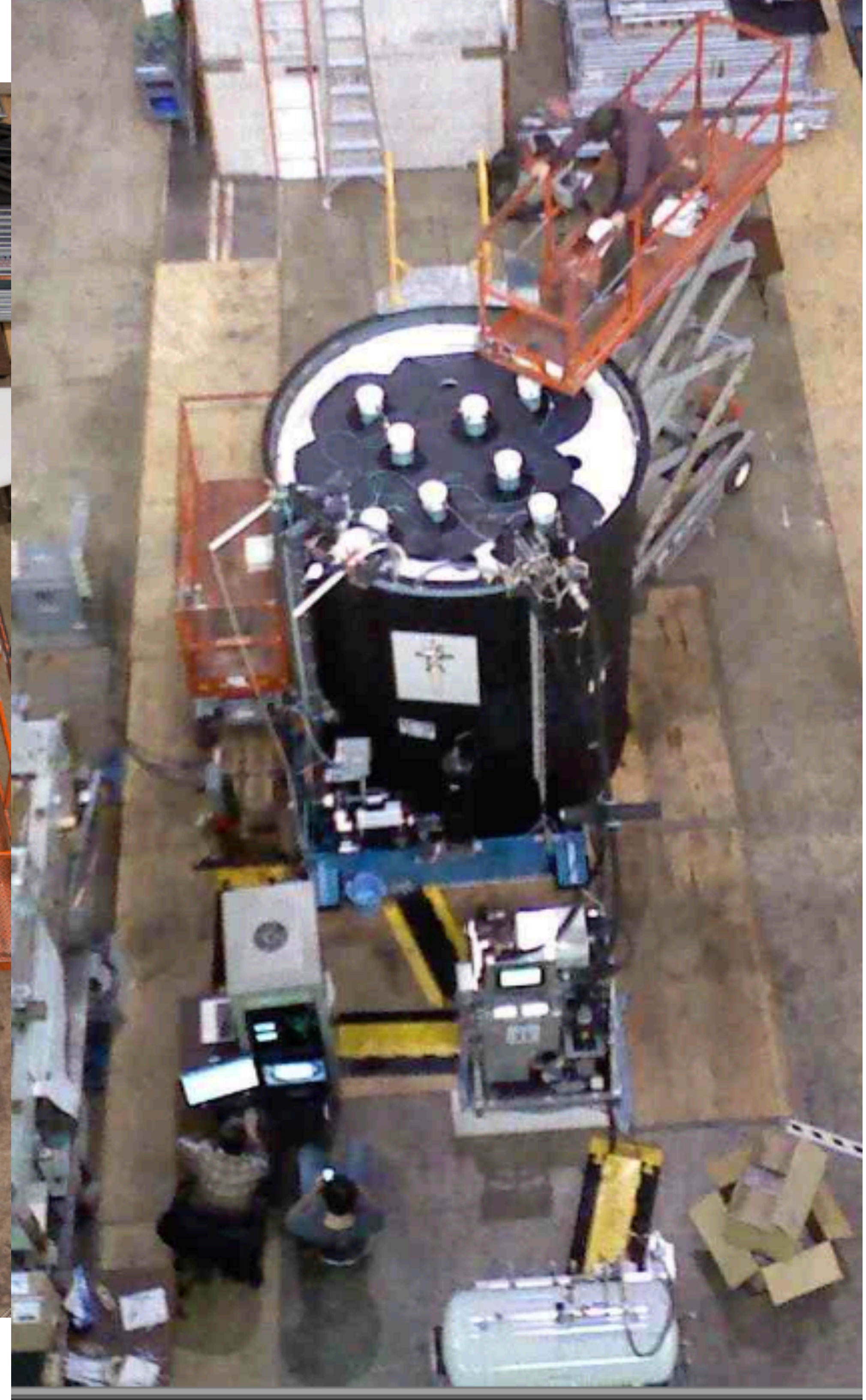
E-961 progress: 60kg chamber construction







COUPP-60 Commissioning

- Chamber operated in NuMI gallery from July 28 to August 30.

- Goal: Test fully operating detector before moving to SNOlab.
  - Stability of mechanical systems, DAQ, photography
  - Backgrounds due to internal radioactivity
    - Analysis in progress, rates appear to be low.
  - Acoustic alpha/ nuclear recoil discrimination

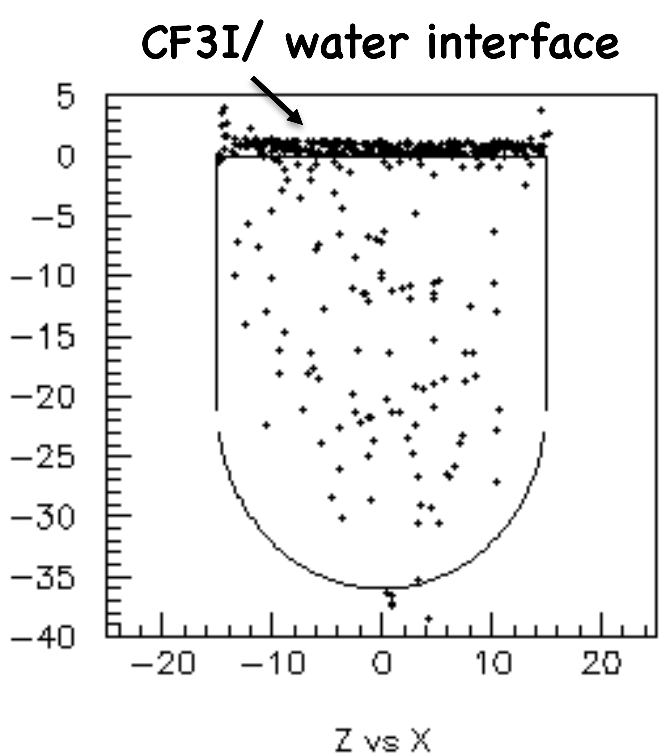
- Several issues discovered, <u>specific of this chamber only</u>.
  - minutiae: leaks, rust control, DAQ, vibrations.
  - relatively minor: illumination issues.
  - deserving serious (ongoing) investigation: interfacial events, photolysis of CF_3I under new illumination scheme (other possible origins also under simultaneous investigation).

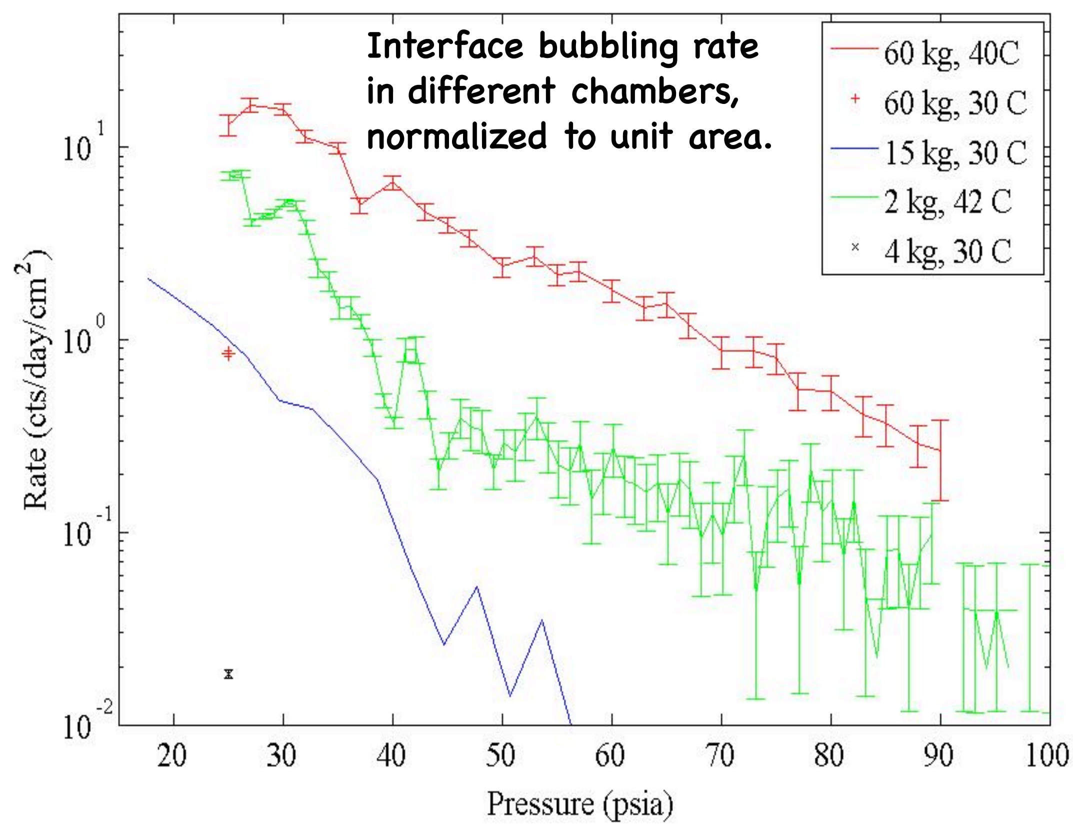
Excess Bubbling at Water/ CF_3I Interface

- Issue has existed at some level in all COUPP chambers, but COUPP-60 is the worst.

- Cause is not known yet. Homogeneous nucleation at the interface theoretically expected to be infinitesimal.
  - Possibilities: Dissolved gas in water, particulate floating on interface, chemical contaminant forming a separate phase film at interface upon depressurization?

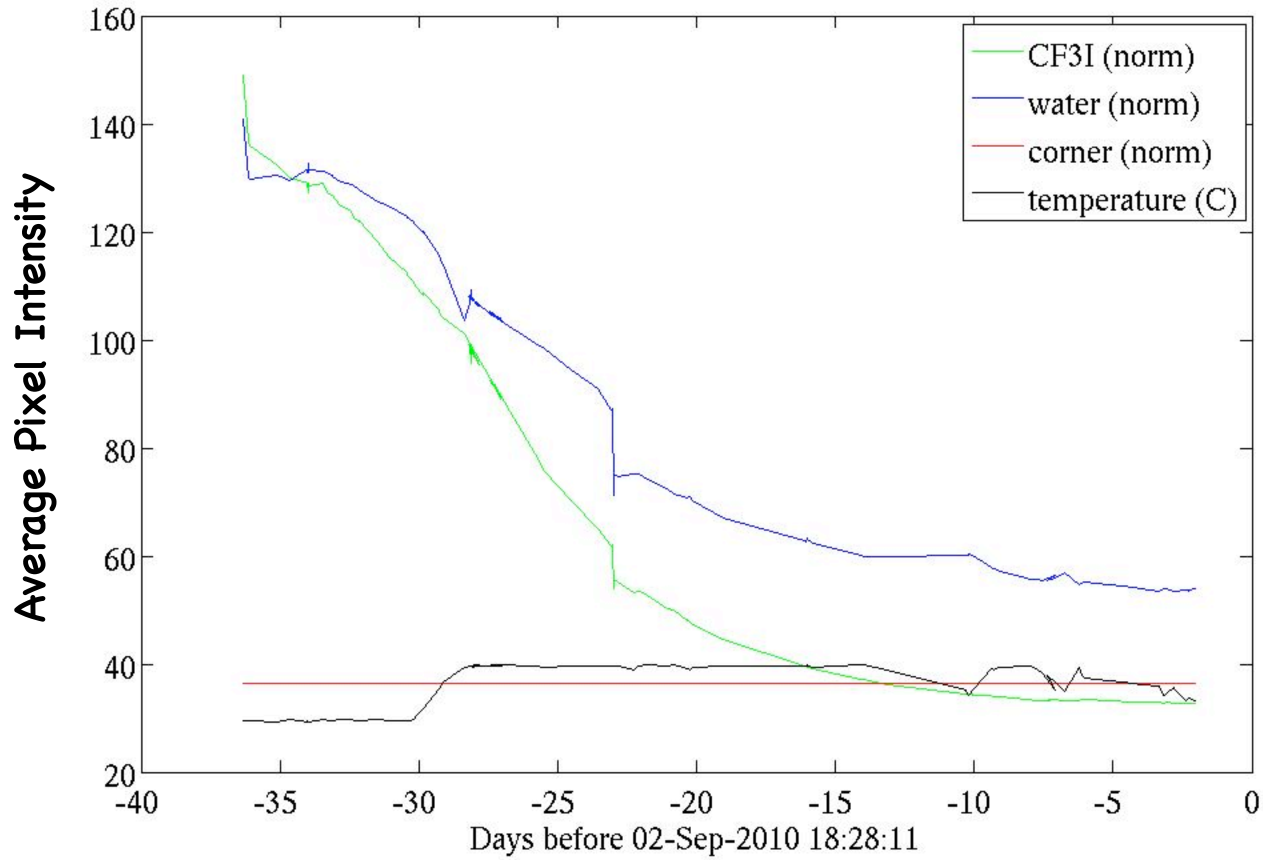
- Consequence is reduction in live time fraction due to 30-60 second compression cycle after each detected bubble. Live fraction reduced to 25% at 40 degrees C presently for this chamber (normally > 80%).





Darkening of Video Images

- Progressive from beginning of run.
- Eventually made data taking impossible.
- Cause was a mystery until we viewed the chamber with white light...



CF_3I decomposition and change in color

Color change indicates the presence of free iodine (I_2) dissolved in chamber liquids.

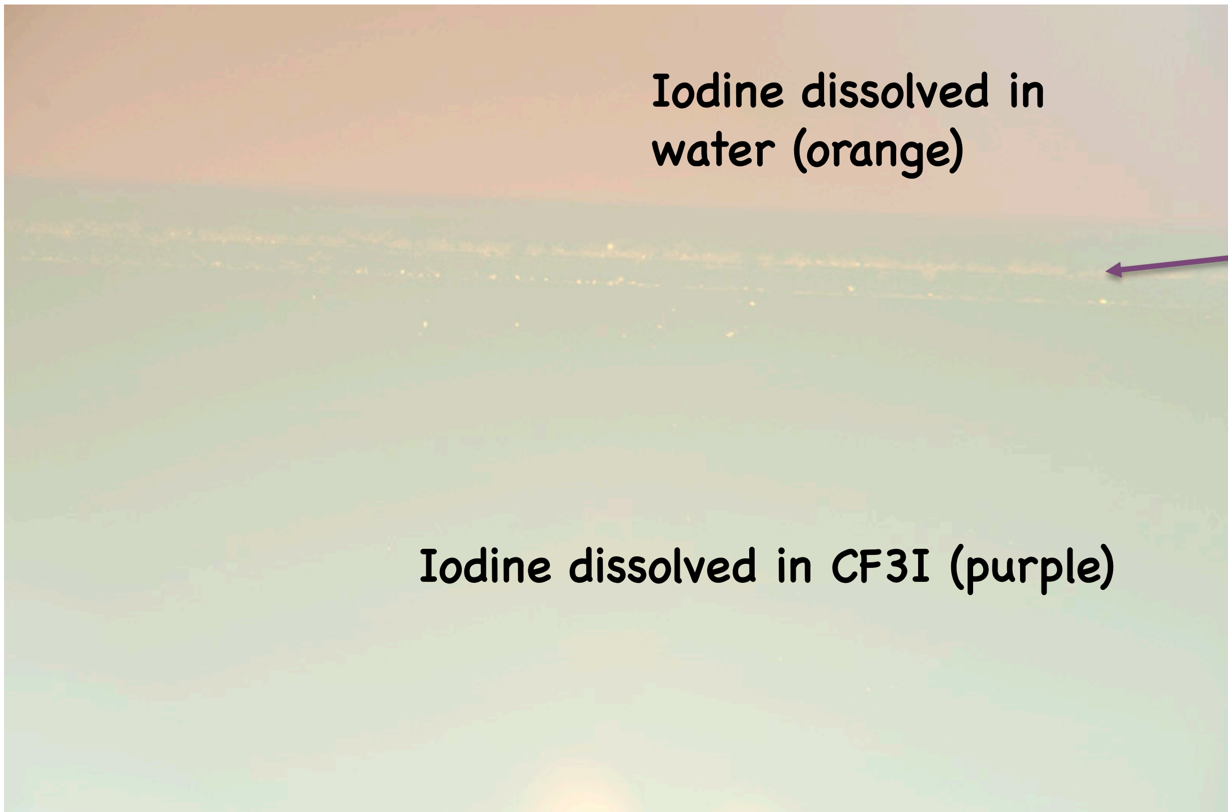


Photo by Raidar Hahn

"ring around the collar" near water/ CF3I interface. Solid contaminant? Bubbles?

Could be cause of surface boiling?

Photodissociation of CF_3I

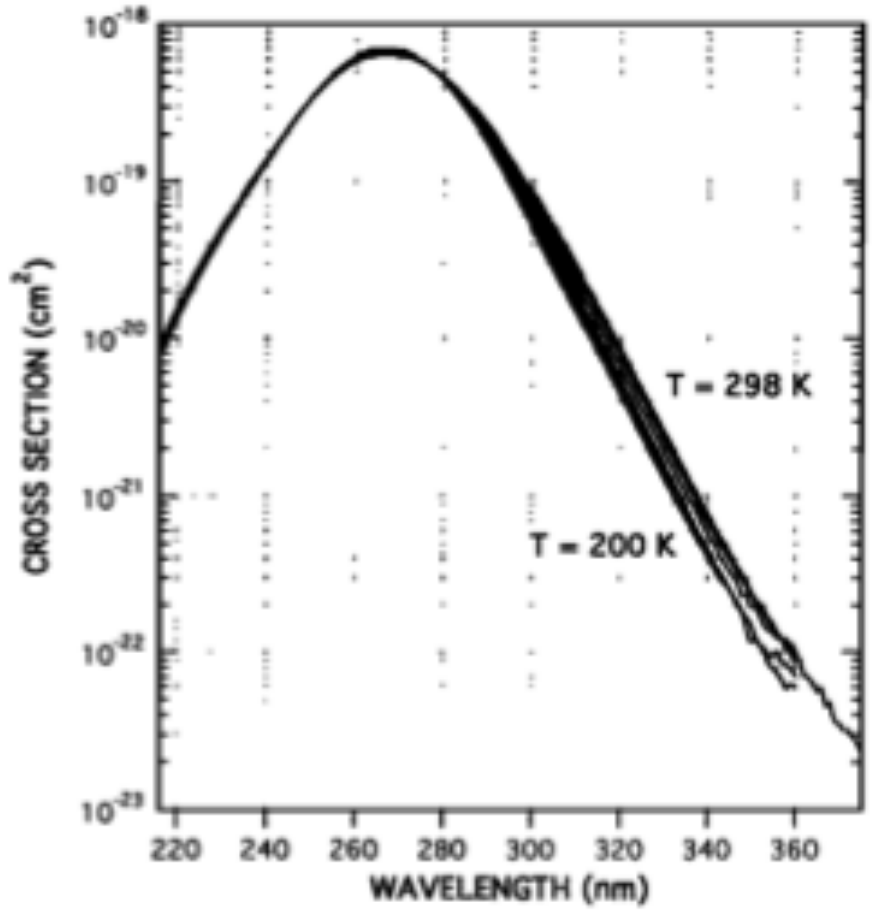
- Destruction of CF_3I molecule by light is well-known and measured at UV wavelengths (leads to use as "green" fire extinguisher)

- Produces free iodine by

  E.g. $2\gamma + 2CF_3I \rightarrow C_2F_6 + I_2$

- We had seen this before in samples exposed to ambient light, but never with red light illumination.

Photolysis of CF_3I



Solomon et al., 1994

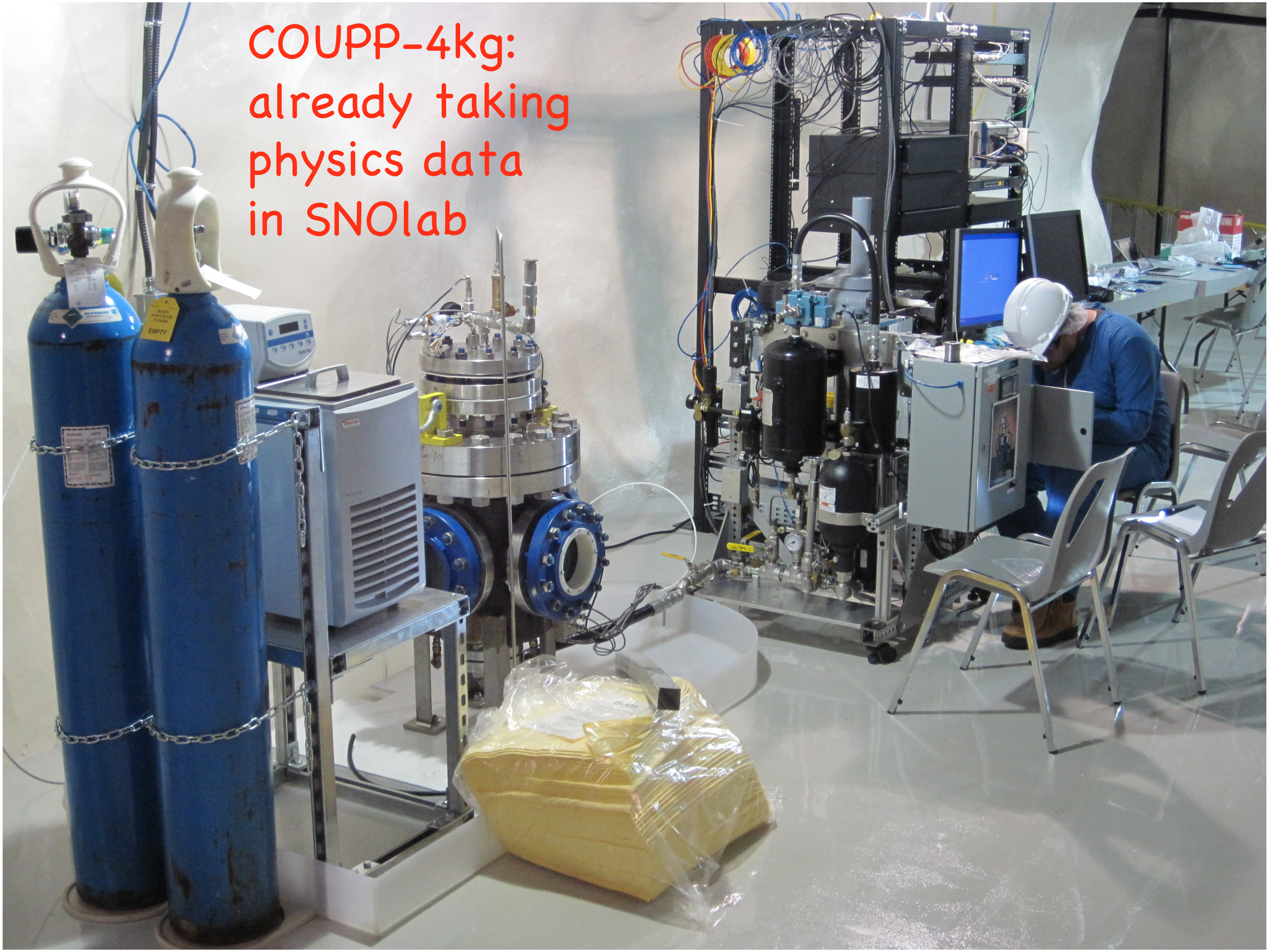
Possible Causes of CF_3I Decomposition

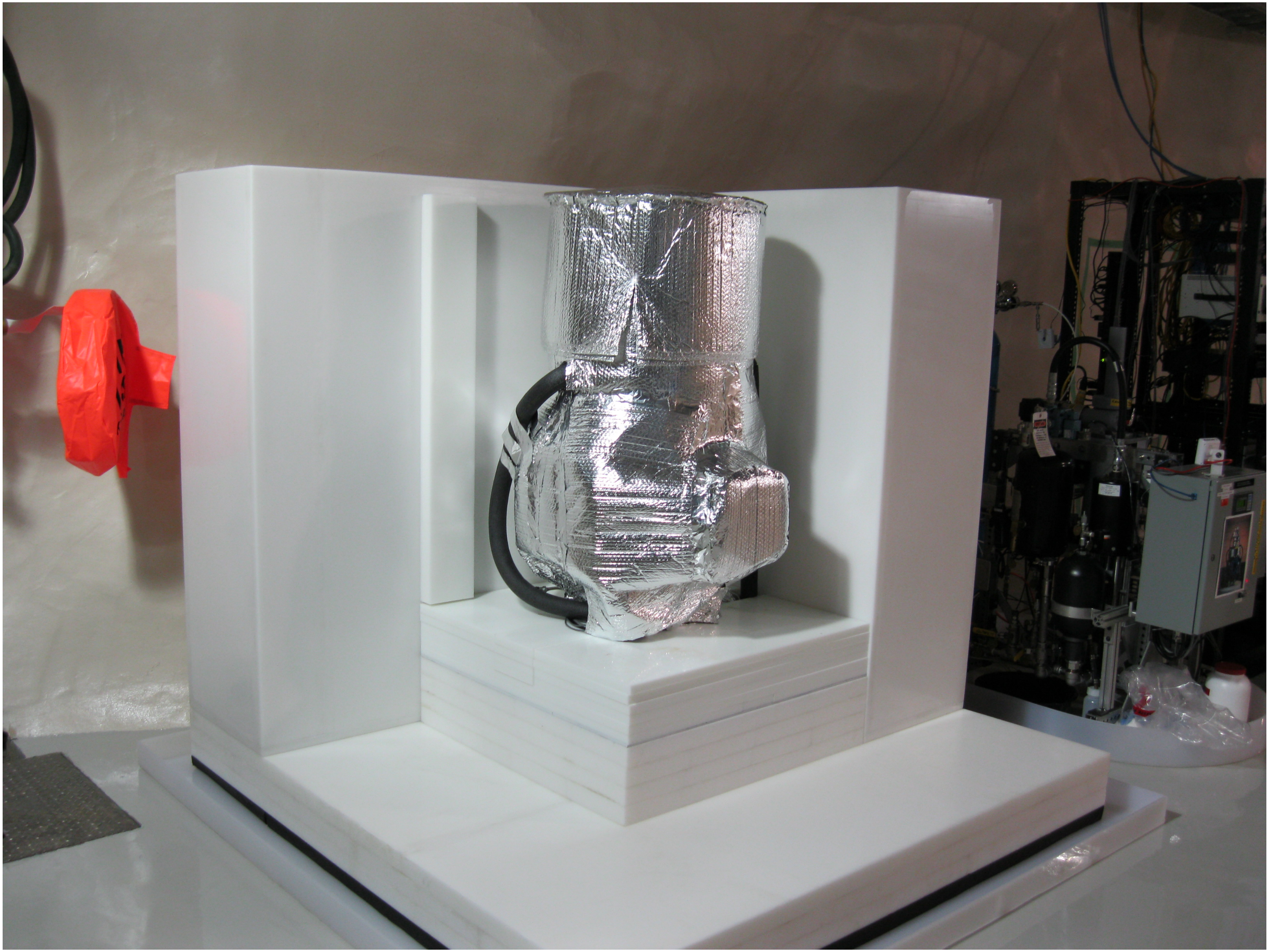
- A light leak? So far we know:
  - Light tightness of the camera package : $<10^{-4}$ of ambient light levels.
  - Some illumination from two green (530 nm) LED indicators on the back of the video cameras.
  - Possible initial exposure to strong halogen lamps during filling.
  - Sheer intensity of red lighting source used
    (continuous illumination, as opposed to synchronized flashes as before)
  - We are exposing samples, should soon know if this is the problem.

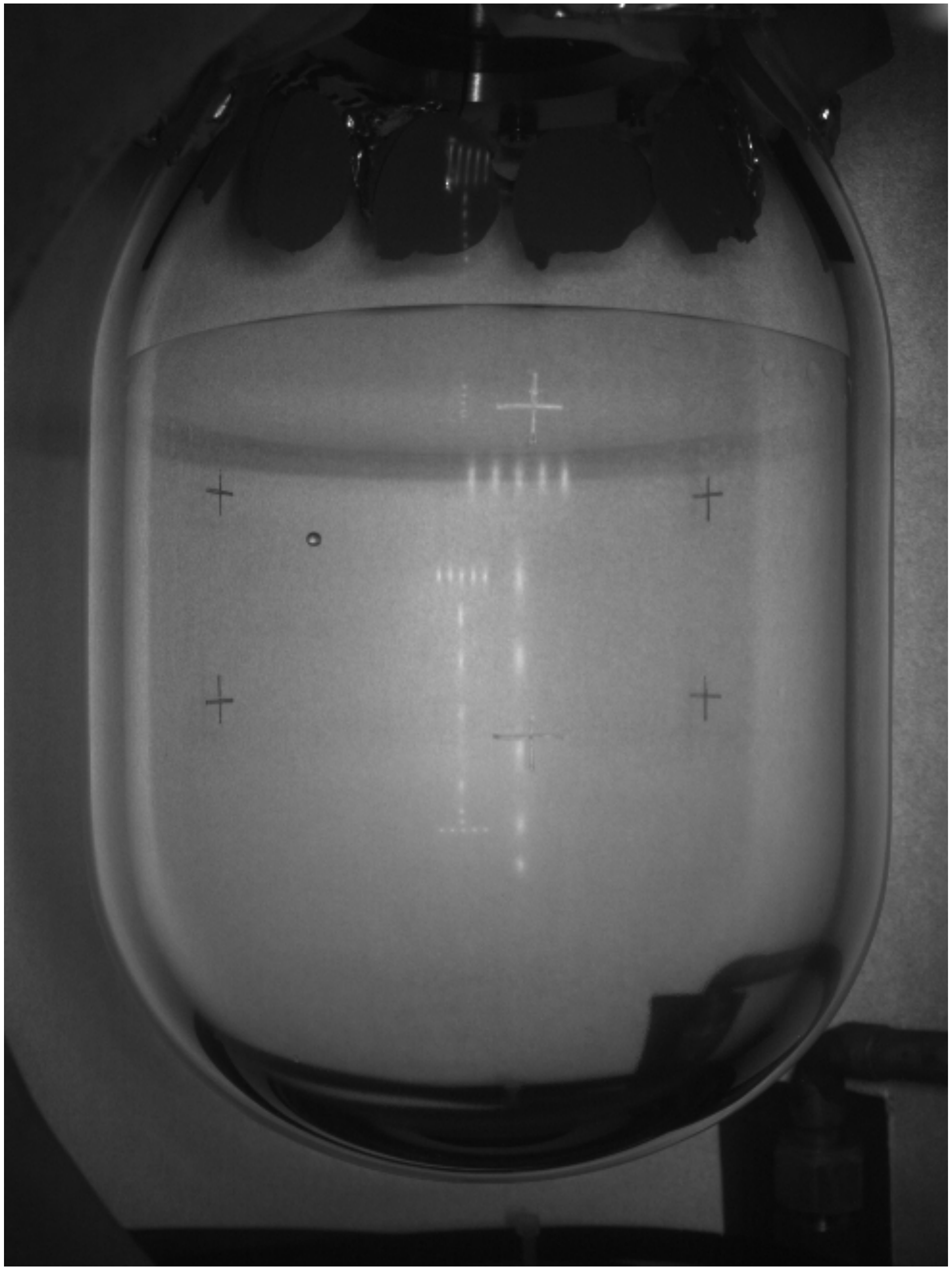
- Incompatibility with chamber materials? Gold O-ring?
  - Gold wire used for stainless to quartz seal for the first time in this chamber.
  - Tests in 2006 at U. Chicago did not see any such problems. Repeating those.

- Chemical impurities in CF_3I?
  - This is a new batch and analysis indicates purity level is less than what we had in the past.
  - Seems unlikely at this point (4 kg chamber at SNOlab using same batch, no issues there)
  - Residue left during cleaning/rinsing? ("ring around the collar", see prev. transparency).

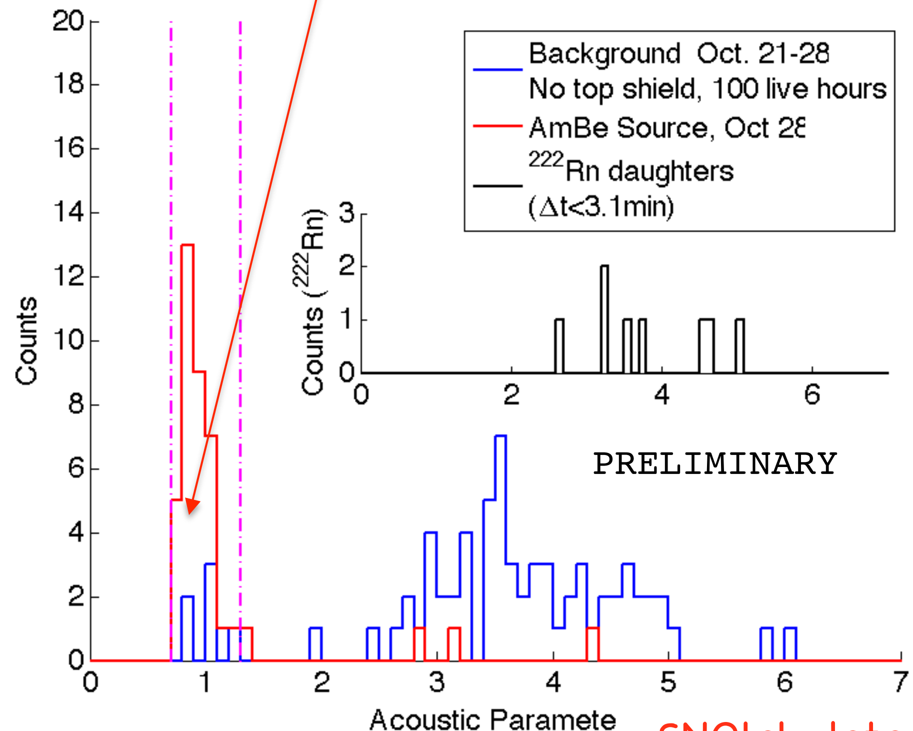
Several "task forces" investigating, should know source soon.


COUPP-4kg:
already taking
physics data
in SNOlab

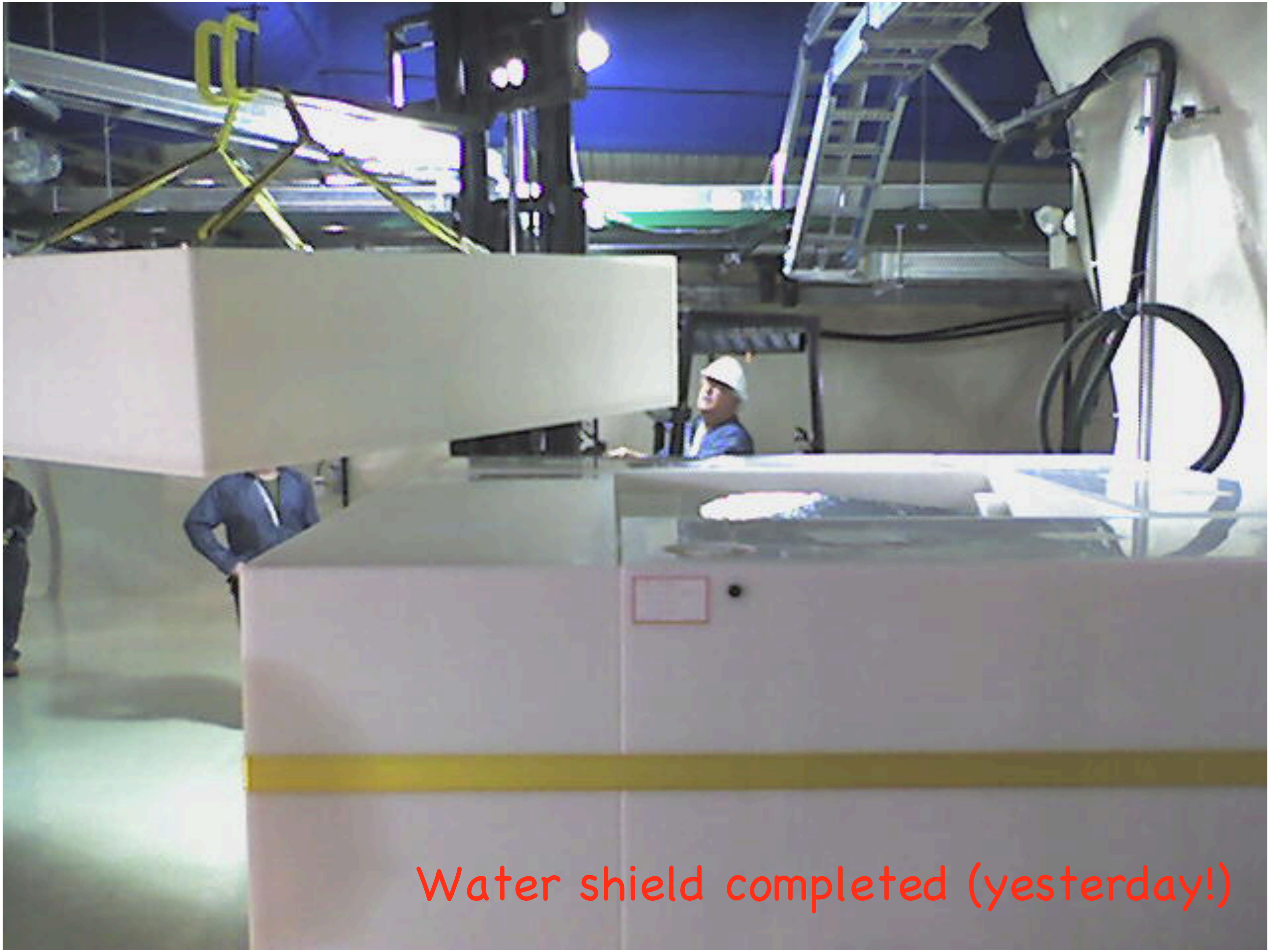




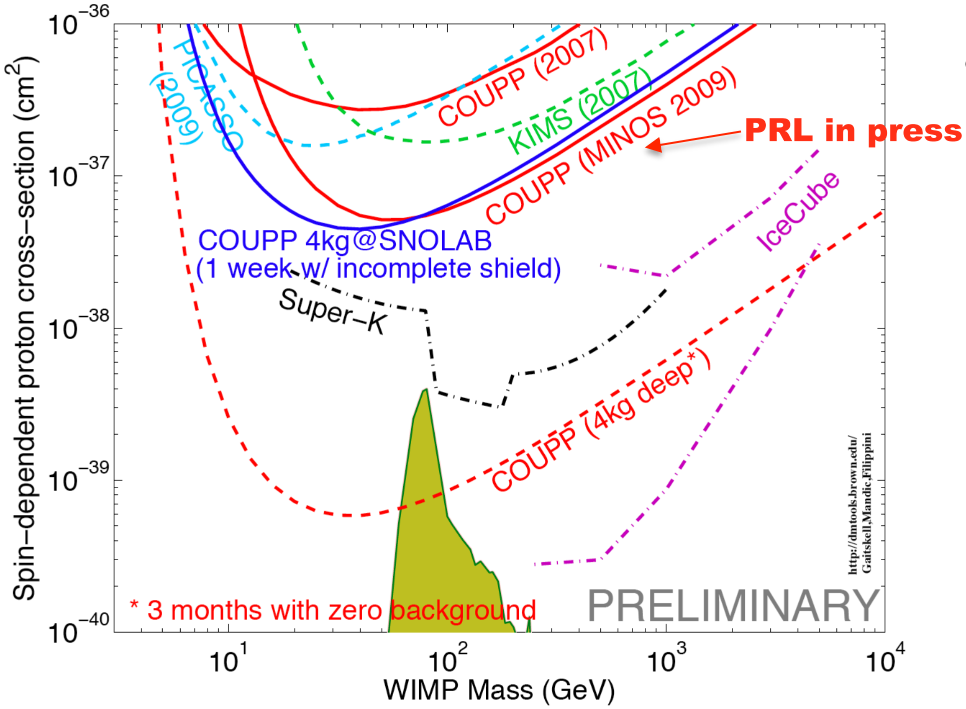
Seeing the
~0.5 neutrons /kg day
expected from a
half-open shield and
~10^{-6} n/cm^2 s

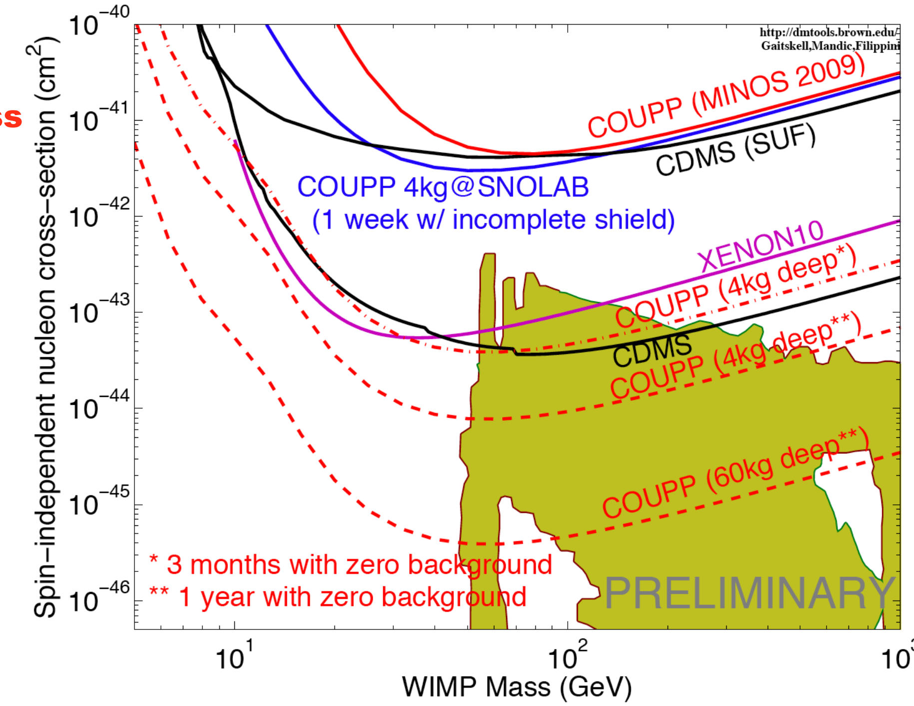


SNOlab data
(last week)


Water shield completed (yesterday!)

The fun has officially started...





- We expect COUPP to be at the forefront of *both* SD and SI WIMP searches during 2011.

- We feel ready for the next step. Collaboration presently enjoys excellent influx of young collaborators (2 grad. students, soon 3.5 postdocs). E.g., we were *talking* about a SNOlab deployment early this summer: we are already taking and analyzing physics data there.

- COUPP-500 design phase already funded by NSF (DUSEL S4). Requesting complementary support from FNAL for same. Construction endorsed by PASAG in *all* funding scenarios (next step, after 60kg debut and performance in SNOlab. Not this proposal).

Present Request to Fermilab

1. Engineering to bring the COUPP-500 proposal to the point where it has a reliable cost estimate
   - 2 FTE engineers in FY11
2. Support for running the 4kg device in SNOLAB
   - In FY11: $30k Travel, $20k M&S, fraction of FTE technician
3. Resources for R&D and Calibration devices to inform the COUPP-500 design
   - In FY11: $140k M&S, 1 FTE technician, fraction of FTE engineer

(Support for the 60kg device is being separately requested in a DOE Fieldwork Proposal)